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Beneficial Use of Stormwater and Land Development Regulation Case Studies in Austin, Texas

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Beneficial Use of Stormwater and Land Development Regulation Case Studies in Austin, Texas

by

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Dedication

To Anita, the love of my life and crutch, without whom graduate school would have been intolerable. Thank you for 'holding down the fort' as I pursued my dreams.

And,

To my late professor Robert Fredrick Young Jr., who could strike a nerve and inspire a chord.

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Abstract

Beneficial Use of Stormwater and Land Development Regulation Case Studies in Austin, Texas

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The University of Texas at Austin, 2018

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Urban development puts strain on the environment in numerous ways. Flora and fauna are pushed off the land, but more immediate to human health, the increase in impervious cover can lead to greater risks of flooding and polluted waters. The City of Austin made a commitment to the environment and managing the city's hydrology in its 2012 Imagine Austin Comprehensive Plan. The city's Watershed Protection Department (WPD) is working to fulfill the city's promise by writing regulation to be included in CodeNEXT, the rewrite of the City's land development code. The aim of this "beneficial use" regulation is to infiltrate, reuse or evapotranspire rainwater that falls on highly impervious multi-family and commercial sites within the city limits. I was hired by the WPD to conduct feasibility studies of their regulation and began by familiarizing myself with Austin's Environmental Criteria Manual (ECM) and the history behind the proposed regulation. I first investigate the extent green stormwater control measures (GSCMs) laid out in the ECM can be implemented on existing sites in the city of varying degrees of impermeability selected by WPD staff. Starting from city archived site plans and shapefiles, I place GSCMs spatially in ArcGIS and use the ECM to determine whether the beneficial use volume threshold set by the city could be met for each site. Finally, I discuss how the findings of my study led to a simplification of the proposed regulation.

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Introduction

When rain falls from the sky, the type of surface the water hits can make a big difference. If the surface is a natural landscape untouched by humans and machinery, a majority of the water will soak into the ground and into plant roots as opposed to flowing elsewhere. If rain falls on an impervious surface like concrete or asphalt, surfaces water doesn't soak into very well, a majority of the water will flow off as stormwater runoff. The United States Environmental Protection Agency has documented the effects too much runoff can have on waterways. The increased amount of water flowing into urban waterways can cause erosion and flooding "damaging habitat, property, and infrastructure."[1] Stormwater runoff from developed and inhabited areas can also carry "trash, bacteria, heavy metals, and other pollutants"[2] into urban waterways. Without the proper measures, waterways will no longer resemble a natural landscape.

Austin has a history of protecting its waterways with regulation in the form of watershed ordinances. These ordinances include: "stream and sensitive environmental feature setbacks; floodplain and erosion hazard protections; requirements for flood detention and water quality treatment; and impervious cover limits."[3] Waterway health is the goal, with the health of some watersheds being more susceptible to harm.

The first ordinance to pass was The Waterway Ordinance in 1974, which was "ahead of its time for US and Texas regulations."[4] This called for flood detention requirements and a bar on human manipulation of waterways. The Comprehensive Watersheds Ordinance of 1986

[1] US EPA. (2017, August 14). What is Green Infrastructure?.
[2] Ibid.
[3] Watershed Protection Department. (n.d.). Watershed Ordinance History.
[4] Ibid.

brought water quality protection to all suburban watersheds in the city. Urban watersheds were brought under protection in 1991 with The Urban Watersheds Ordinance. The Save Our Springs Ordinance, the City's hallmark environmental regulation, came in 1992. It is a very stringent ordinance that protects the Barton Springs zone by severely limiting development and allowing no exceptions to the rules. The Watershed Protection Ordinance (WPO) of 2013 came as a "comprehensive overhaul of Austin's environmental and drainage code."[5] With this ordinance, protection to land bordering waterways was extended to smaller creeks and streams in the city. At the same time the ordinance made development easier, by allowing for certain variances in Critical Water Quality Zones.[6] The WPO marked the completion of Phase 1 of changes to the city's watershed regulations called for by the Imagine Austin Comprehensive Plan.

Phase 2 was started when the Green Infrastructure Working Group of public stakeholders met between January and June of 2015. The group was brought together to help determine how Austin would implement one of its Imagine Austin Comprehensive Plan Priority Programs: "use green infrastructure to protect environmentally sensitive sreas and integrate nature into the city."[7] Specifically, the Working Group discussed land cover, beneficial use of stormwater and stormwater options for redevelopment/infill and helped develop watershed protection recommendations for the Natural and Built Environment Code Prescription for the city.[8] [9]

Current Austin code requires varying amounts of stormwater runoff at differing levels of impervious cover to be captured, treated and released after 48 hours. The water is slowed and cleaned but more could be done to, as the code prescription states, "enhance creek base flow,

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[5] Watershed Protection Department. (n.d.). Watershed Ordinance History.
[6] Watershed Protection Department. (2013). Watershed Protection Ordinance Summary of Code Improvements.
[7] City of Austin. (n.d.). Green Infrastructure.
[8] Watershed Protection Department. (n.d.). Watershed Protection Ordinance.
[9] Watershed Protection Department. (n.d.). Watershed Ordinance History.

[support] on-site vegetation, and reduce potable water consumption."[10] According to the prescriptions listed, new and redeveloped sites should be required to capture and "beneficially use" stormwater onsite.[11] Furthermore, 95% of all rain events (less than 1.8 inches of rainfall at one time) should be infiltrated, taken up by plants or harvested for use. The code prescription suggests that green stormwater control measures (GSCMs) be used to achieve these goals.[12]

This document would then inform Austin's draft land development code rewrite, CodeNEXT, released in 2017. Draft 1 of CodeNEXT required beneficial use of stormwater based on impervious cover and the 95th percentile rainfall as mentioned in the code prescription. However, the required beneficial use volumes and the practices to achieve beneficial use were not specified.[13]

The Watershed Protection Department (WPD) then started to lay out specific beneficial use volumes based on impervious cover, to more resemble the city's requirements for minimum water quality volume. The required water quality volume starts at 0.5 inches and increases by 0.1 inch every 10% impervious cover on site over 20% impervious cover.[14] Although also based on the 95th percentile rainfall, the beneficial use volume would instead increase by roughly one eighth inch for every 10% impervious cover on site. Both volumes would be roughly equal at 100% impervious cover. The department needed to conduct studies to see if these parameters for beneficial use were reasonable, so WPD hired me to do those studies during the summer of 2017.

[10] City of Austin. (2016). The Next Austin: Manage our growth, keep our character.
[11] Ibid.
[12] Ibid.
[13] City of Austin. (2017, January). Land Development Code Draft 1.0. CodeNEXT. 3D-6 p. 2
[14] City of Austin. (n.d.). 1.6.0 - Design Guidelines For Water Quality Controls. Environmental Criteria Manual

Methods

The Watershed Protection Department gave me instruction to attempt to achieve beneficial use requirements on five existing sites in the City of Austin. The spatial distribution of each site within the city can be seen in Figure A1. To begin, GIS map files were produced for each site. Most sites had already been digitized, with georeferenced site plans, by Watershed Protection Department GIS staff. If not, I traced the building footprint, pavement and major landscaping features into shapefiles. For all sites, I added the parcel boundary, road alignment and soil area shapefiles. More shape files were added as I determined what GSCMs were applicable on site. Figures showing final versions of each map can be found in the Appendix.

To begin the GSCM selection process, a desktop soil study was done to estimate how well site soils would drain water in the event of rainwater ponding. The Travis County Soils shapefile listed what soil map units make up the site, or if the site was Urban Land, what soils surrounded the site. Soil map unit descriptions were pulled from the Natural Resources Conservation Service website. Map unit composition, typical profile, depth to water table and limiting layer hydraulic conductivity were the most pertinent information. An average hydraulic conductivity was calculated from the minimum and maximum provided. The depth to the water table was taken as is. An estimate depth to bedrock was taken from the depth listed in the typical profile. Map unit composition was used to calculate weighted average estimates of hydraulic conductivity and bedrock depth if necessary. Surrounding soils information was used to calculate similar estimates for Urban Land soil, where little information is known. The Urban Land soil map unit generally means that the top soil is compacted fill accumulated from development and redevelopment.

This information was then used to determine what GSCM could be successfully implemented on site. The use of certain GSCMs were disqualified first by comparing the depth to bedrock and water table on the site against depth requirements listed in the City of Austin Environmental Criteria Manual (ECM). For porous pavement, the minimum depth should be 22 inches. Vegetative filter strips require just a depth of 12 inches. The depth requirements for rain gardens are more complicated. Depth requirements and illustrative specifications in the ECM were synthesized into Table 1. Type of rain garden, modification of rain garden into planter box and ponding depth all change the depth requirements. Modifying rain gardens into planter boxes takes advantage of the 12 inch depth minimum. Full filtration ponds have no requirements based on soil depth.[15]

Table 1: Minimum Allowable Depth to Bedrock or Groundwater Table with Varying Rain Garden Types and Ponding Depth

		Depth to Bedrock/Groundwater Table (in)			
	Max Ponding Depth (in)	Full Infiltration Rain Garden	Partial Infiltration Rain Garden	Full Filtration* Rain Garden	*To avoid: digging through bedrock, etc.
Rain Gardens	3	21	45	0*	33
	6	24	48	0*	36
	9	27	51	0*	39
	12	30	54	0*	42
Planters	3	12	12	0	
	6	12	12	0	
	9	12	12	0	
	12	12	12	0	

Soil map units then had to be checked for appropriate hydraulic conductivity to ensure infiltration of rain water. As specified by the ECM, the soil design hydraulic conductivity is half of the measured, or in this case average, soil hydraulic conductivity. This equates to a safety

[15] City of Austin. (n.d.). 1.6.7 - Green Storm Water Quality Infrastructure. Environmental Criteria Manual

factor of 2. To be conservative, a factor of 3 was used for Urban Land soil design hydraulic conductivity. In addition to a depth to bedrock of 22 inches, the soil hydraulic conductivity must be at least 0.20 in/hr for porous pavement to be allowed on site. Otherwise, design hydraulic conductivity was multiplied by a 48 hour drawdown time to determine the ponding depth a full infiltration rain garden can accommodate. The ponding depth was rounded down to 12, 9, 6 or 3 inches. More information was required before GSCMs could be placed.[16]

Site plans also provided important information. The total building and payment area numbers were confirmed on the site plans. Elevation data also informed where runoff from pavement collected. Rain gardens were only placed where they could actually collect water. Drainage calculations of how much water went to each individual rain garden were not done however. Porous pavement is best used on areas of high elevation compared to the site and were not be placed where water could accumulate, such as next to stormwater inlets.

In placing GSCMs on the sites, some general assumptions were made. Sites would not be credited for GSCMs in the public right-of-way. Evapotranspiration, or water absorption by plants, would not be figured into beneficial use calculations because research on its effects on rain gardens is wanting. It is more conservative to leave it out as well. Rooftop and pavement would be treated as two separate flow sources. Multiple scenarios were completed: at the least, one where actual conditions were conservatively estimated and one for ideal conditions. Ideal conditions mean soil types are not determinants of GSCMs characteristics and right-of-way gets included.

Based on price and ease of installation, a hierarchy was created for placing GSCMs on each site. First, rain gardens of appropriate type were placed on the site in GIS where possible

[16] City of Austin. (n.d.). 1.6.7 - Green Storm Water Quality Infrastructure. Environmental Criteria Manual

(parking medians, open space, landscaping, etc.) based on soil conditions and site drainage. Ponding depths were determined using Table 1. Rain gardens were given beneficial use credit for the volume of water that would be captured during a short, high intensity rain event. For infiltration rain gardens, the volume of maximum ponded water and the volume of water held in the soil media during maximum ponding were counted. For partial infiltration rain gardens, the volume of water held in the void space of the soil media, above and below the underdrain was counted. After a short, high intensity rain event, water would only be left in the soil media. Full filtration rain gardens would only get credit for soil media void space because there are no saturated zones underneath the underdrain in this type of rain garden. Soil media, not gravel, could be added to a practical extent to rain gardens to earn more credit. Soil media void space was assumed to be 24% of the soil volume. In some instances, planter boxes were made into rain gardens to work with limited space and/or shallow soil depths on site.

Second, porous pavement was placed according to appropriate soil and elevation conditions discussed earlier. Porous pavement captures only the maximum beneficial use rainfall depth (1.28 inches), similar to the design for water quality. This is equivalent to the porous pavement capturing the first flush of rain, despite the required void space under it being capable of storing slightly more water.

Third, potential for rain water harvesting, usually from the total roof area but also possible from pavement area, was examined. The captured water volume equaled the beneficial use rainfall depth over the catchment area. Using occupancy numbers from site plans and estimates of average daily bathroom water use per person, estimates for the potential for indoor use of stormwater over a 5-day drawdown time were calculated. Indoor water usage estimates were provided by a coworker. Then the volume of water that could be irrigated to landscaping, or rain gardens if they weren't full filtration, was determined. Irrigation rates, capped at 0.20 in/hr, were multiplied by the 108 hour maximum irrigation period over the entire irrigation area, to calculate the total credited irrigation volume.[17] The option of using vegetative filter strips was explored only on one site and will be included in the full discussion of that site.

Last, the remaining captured rainwater was used to determine if a green roof was needed to provide additional irrigation area. Green roofs were the last resort, as they are hard to maintain and are very often cost-prohibitive.

Once all GSCMs were placed, a check was made to see if the desired beneficial use volume was achieved. If the goal was not met, parameters and shapefile areas were tweaked to achieve the goal if possible. The same process of siting GSCMs was repeated for a scenario of ideal soil conditions where bedrock and proper infiltration would not be concerns. Exhibits showing both scenarios for each site and the GSCMs used can be found in Appendix.

[17] City of Austin. (n.d.). 1.6.7 - Green Storm Water Quality Infrastructure. Environmental Criteria Manual

Results

The first case study was the Balcones Ranch Apartments located at 13145 North US Highway 183. It is an apartment complex of low-rise apartments spread out over 12.17 acres. Impervious cover accounts for 6.71 of those acres. The required water quality volume is 35,427 cubic feet, and the proposed beneficial use volume would be 31,211 cubic feet.

Table 2 and Figure A2 displays the GSCMs used under actual site conditions for the Balcones Ranch Apartments. There are three soil map units in the site, each with differing suitability for GSCMs: full infiltration planters with a 6 inch ponding depth and vegetative filter strips on the Eckrant extremely stony clay (EeB), partial infiltration planters on the Crawford clay (CfB), and partial infiltration ponds on the Fairlie clay (FaB). Car ports, buildings and sections of pavement made up drainage areas to rain gardens. The rest of pavement runoff would be stored in an underground tank for landscaping irrigation. Rainwater from rooftops would feed rain gardens in the landscaping area and released slowly from rainwater harvesting tanks onto vegetative filter strips if necessary.

Table 3 and Figure A3 displays the GSCMs used under ideal site conditions for the Balcones Ranch Apartments. All full infiltration rain gardens and porous pavement could be used to simply achieve beneficial use requirements.

Table 2: Use of GSCMs Under Actual Site Conditions for the Balcones Ranch Apartments

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Pavement	Rain Gardens	3,612	0.23
	Rainwater Harvesting: Landscaping*	14,499	0.46
Roof	Rain Gardens	12,819	0.52
	Rainwater Harvesting: Vegetative Filter Strip	5,085	0.24
Total		36,014	0.99

*Land not solely for GSI is not counted in the land area total

Table 3: Use of GSCMs Under Ideal Site Conditions for the Balcones Ranch Apartments

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Pavement	Infiltration Rain Gardens	16,486	0.59
	Porous Pavement*	2,114	0.46
Roof	Infiltration Rain Gardens	21,325	0.76
Total		39,925	1.34

*Land not solely for GSI is not counted in the land area total

The second case study was the Glazer's Wholesale Distributors located at 8119 Exchange Drive. It is a large warehouse siting on 13.55 acres. Impervious cover accounts for 9.73 of those acres. The required water quality volume is 44,924 cubic feet, and the proposed beneficial use volume would be 45,49 cubic feet.

Table 4 and Figure A4 displays the GSCMs used under actual site conditions for the Glazer's Wholesale Distributors. There are three soil map units in the site, each with differing suitability for GSCMs: porous pavement, full/partial infiltration planters, vegetative filter strips on the Gravel Pits (GP) and Urban Land, Austin, and Whitewright soils (UtD), and partial infiltration or full filtration ponds on Houston Black soils and Urban Land (HsD). All rainwater falling on the roof must be collected in cisterns. First the roof would act to capture water in 3 inches of gravel (blue roof), overflow from the roof would flow into 2 cisterns which in turn outfall into 2 surface level rain gardens. Only part of the site could capture its own runoff in porous pavement. To boost the amount of water captured from the pavement, credit was given to the media void space in the existing water quality ponds on site.

Table 5 and Figure A5 displays the GSCMs used under ideal site conditions for the Glazer's Wholesale Distributors. Better soil allowed more rain gardens in parking medians, however some green roof (or complete blue roof) and water quality media void space credit were still necessary to meet the beneficial use requirement.

Table 4: Use of GSCMs Under Actual Site Conditions for Glazer's Wholesale Distributors

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Pavement	Media Void Space*	5,856	0.37
	Porous Pavement*	1,122	0.24
Roof	Blue Roof*	15,600	4.78
	Infiltration Rain Gardens	4,427	0.12
	Rainwater Harvesting	1,412	0.003
Total		28,418	0.12

*Land not solely for GSI is not counted in the land area total

Table 5: Use of GSCMs Under Ideal Site Conditions for the Glazer's Wholesale Distributors

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Pavement	Media Void Space*	5,856	0.59
	Porous Pavement*	4,431	0.95
	Infiltration Rain Gardens	13,479	0.28
Roof	Green Roof*	14,976	4.78
	Infiltration Rain Gardens	7,812	0.16
Total		46,554	0.44

*Land not solely for GSI is not counted in the land area total

The third case study was the Villas on Sixth Apartments located at 2011 East 6th Street. It is an apartment complex of low-rise apartments on a compact 6.09 acres. Impervious cover accounts for 4.64 of those acres. The required water quality volume is 23,466 cubic feet, and the proposed beneficial use volume would be 21,675 cubic feet.

Table 6 displays the GSCMs used under actual site conditions for the Villas on Sixth Apartments. There is only one soil map unit on this site: Urban Land. Surrounding soils, Houston Black soils and Urban Land (HsD), Travis soils and Urban Land (TuD), Bergstrom soils and Urban Land (Bh) and Urban Land, Austin, and Whitewright soils (UtD) were combined in a composite average to estimate soil properties for the site. Even with a safety factor of 3, the design hydraulic conductivity allowed for porous pavement and full infiltration ponds. All sidewalk was made porous. All parking medians and landscaping was made into full infiltration ponds.

Table 7 displays the GSCMs used under ideal site conditions for the Villas on Sixth Apartments. Nothing changed in terms of what GSCMs could be used. Barring constraints, the amount of rainfall capture was doubled. Figure A6 shows the layout of GSCMs under both ideal and actual conditions.

Table 6: Use of GSCMs Under Actual Site Conditions for the Villas on Sixth Apartments

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Pavement	Rain Gardens	13,625	0.51
	Porous Pavement*	1,849	0.40
Roof	Rain Gardens	10,456	0.39
Total		25,930	0.91

*Land not solely for GSI is not counted in the land area total

Table 7: Use of GSCMs Under Ideal Site Conditions for the Villas on Sixth Apartments

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Pavement	Infiltration Rain Gardens	27,250	0.51
	Porous Pavement*	1,849	0.40
Roof	Infiltration Rain Gardens	20,913	0.39
Total		50,012	0.91

*Land not solely for GSI is not counted in the land area total

The fourth case study was the Post South Lamar Apartments located at 1500 South Lamar Boulevard. It is amid-rise apartment complex on 4.04 acres. Impervious cover accounts for 3.26 of those acres. The required water quality volume is 17,819 cubic feet, and the proposed beneficial use volume would be 15,237 cubic feet.

Table 8 and Figure A7 displays the GSCMs used under actual site conditions for the Post South Lamar Apartments. Urban Land makes up a majority of the site so composite properties were created from surrounding soils: Eddy soils and Urban Land (EuC) and Urban Land, Austin, and Whitewright soils (UtD). The composite soil, after a hydraulic conductivity safety factor of 3, allowed partial infiltration planters and vegetative filter strips. Rain gardens were put in parking medians and open spaces where ever drainage allowed. The underground sand filter was converted into a vault for indoor use and irrigation to rain gardens and green roof.

Table 9 and Figure A8 displays the GSCMs used under ideal site conditions for the Post South Lamar Apartments. Ideal soil conditions allowed the addition of pervious pavement in places of higher elevation.

Table 8: Use of GSCMs Under Actual Site Conditions for the Post South Lamar Apartments

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Pavement + Roof	Rainwater Harvesting: Indoor Use*	250	0.00
	Rainwater Harvesting: Rain Gardens	3,692	0.06
	Rainwater Harvesting: Green Roof*	13,886	0.18
Total		17,828	0.06

*Land not solely for GSI is not counted in the land area total

Table 9: Use of GSCMs Under Ideal Site Conditions for the Post South Lamar Apartments

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Pave.	Porous Pavement*	984	0.21
Pavement + Roof	Rainwater Harvesting: Indoor Use*	350	0.00
	Rainwater Harvesting: Rain Gardens	16,569	0.21
	Rainwater Harvesting: Green Roof*	909	0.01
Total		18,812	0.21

*Land not solely for GSI is not counted in the land area total

The fifth case study was the Galileo at 25th Condominiums located at 910 West 25th Street. It is a mid-rise private student housing building on a small 0.33 acres. Impervious cover accounts for 0.30 of those acres. The required water quality volume is 1,410 cubic feet, and the proposed beneficial use volume would be 1,386 cubic feet.

Table 10 and Figure A9 displays the GSCMs used under actual site conditions for the Galileo at 25th Condominiums. There is only one soil map unit on this site: Austin-Urban Complex (UsC). This soil allowed full infiltration ponds, porous pavement and vegetative filter strips. All landscaping area within the property was made into full infiltration ponds. There were no real opportunities for porous pavement on site. The underground sand filter was converted into a vault for indoor use and irrigating the rain gardens and green roof.

Table 11 and Figure A10 displays the GSCMs used under ideal site conditions for the Galileo at 25th Condominiums. In this case, use of public right-of-way expanded the full infiltration ponds, therefore the green roof was no longer necessary.

Table 10: Use of GSCMs Under Actual Site Conditions for the Galileo at 25th Condominiums

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Roof	Rainwater Harvesting: Indoor Use*	100	0.000
	Rainwater Harvesting: Rain Gardens	610	0.012
	Rainwater Harvesting: Green Roof*	699	0.009
Total		1,409	0.012

*Land not solely for GSI is not counted in the land area total

Table 11: Use of GSCMs Under Ideal Site Conditions for the Galileo at 25th Condominiums

Source	GSCM Type	BUV Provided (cf)	GSCM Area (ac)
Roof	Rainwater Harvesting: Indoor Use*	150	0.000
	Rainwater Harvesting: Rain Gardens	2,030	0.012
Total		2,180	0.012

*Land not solely for GSI is not counted in the land area total

Discussion

Results for each site are summarized by ascending impervious cover levels in Table 12 for the actual scenario and Table 13 for the ideal scenario. Ratios for were calculated to show the percentage of the beneficial use goal met and the percentage of site area consumed by GSCMs. Land where existing impervious cover was replaced by GSCMs was not considered to be consumed, or area that is not part of the planned development.

The Balcones Ranch Apartments exceeded the beneficial use requirements with GSCMs in the abundant landscaping and parking median area, despite the less than ideal soil conditions and large area taken up by the detention pond. The area consumed by GSCMs was 8%, larger than the roughly 5% consumed by the detention pond but much less concentrated. With completely draining soils, a site of such density would easily meet beneficial use requirements without more complicated irrigation systems. More rain gardens would increase the amount of area consumed.

Glazer's Wholesale Distributors proved to be the most challenging site. Compared to the required beneficial use requirement, very little volume could be captured from the site surface, leading to only 1% consumed land area. The warehouse was placed primarily on more well-draining soils than not, forcing more capture on the roof. The entire roof would need to be green roof to meet the site goal. The roof of a warehouse would not normally be able to hold the added weight of soil. Instead, holding a few inches of gravel and water seemed to more closely resemble normal building function. This measure helped, but the goal could not be met. Ideal conditions remedied the soil problems but the with the site layout problems nonetheless contributed to the goal just narrowly being met. Conveyance channels exist outside the property boundaries which could potentially contribute to the rainfall captured, legalities permitting.

Of all sites, Villas on Sixth met beneficial use requirements most easily. The soil and site layout allowed for plenty of area for infiltration, which accounted for 15% consumed land area. Since over twice the beneficial use goal was achieved under ideal conditions, the consumed area could at least be reduced to 8%.

For the Post South Lamar Apartments, it made the most sense to capture the water quality volume, in the underground sand filter turned vault, simultaneously meeting water quality and beneficial use requirements. Soils restricted certain areas from being irrigated rain gardens, so the amount of land consumed was only 1% of the site. Under ideal conditions, additional rain gardens and the addition of pervious pavement could not prevent the need for a green roof. The additional rain gardens increased the amount of consumed land.

The most impervious site, the Galileo at 25th Condominiums, had a system like that of Post South Lamar Apartments. However, in this case the green roof would not be necessary if the right-of-way was irrigated. With fully infiltrating soils and use of the right of way, the rain gardens could be allowed to pond, reducing the size of the rainwater harvesting tank needed. The amount of land consumed, 4%, did not change between each scenario since the GSCM area added was not on the property.

Most sites were able to meet their beneficial use goals, despite varying soil conditions. The site that could not, Glazer's Wholesale Distributors, was held back by a combination of less than ideal soils and less than optimal site layout. After conducting all case studies, a general pattern to the method of placing GSCMs emerged. If a site has good soil, multiple buildings and is below 80% impervious cover, rain garden design should come first. This would likely be the most cost-effective method. If a site has less than ideal soils, one building and is above 80% impervious cover, rainwater harvesting design should come first, as rain gardens alone will not suffice. It is hard to say whether beneficial use requirements in general will drastically increase development costs. It is reasonable that a lot of projects will not be able to afford green roof installation for meeting new requirements. Using GSCMs instead of concentrated stormwater management tools like detention ponds could increase the amount of profitable land use on a given site however.

Table 12: Beneficial Use Volume Success Measures Under Actual Site Conditions for Each Location

Site	IC	BUV Ratio: Provided to Required	Area Ratio: GSCM to Site
Balcones Ranch Apartments	55%	115%	8%
Glazer's Wholesale Distributors	72%	63%	1%
Villas on Sixth Apartments	76%	120%	15%
Post South Lamar Apartments	81%	117%	1%
Galileo at 25th Condominiums	91%	102%	4%

Table 13: Beneficial Use Volume Success Measures Under Ideal Site Conditions for Each Location

Site	IC	BUV Ratio: Provided to Required	Area Ratio: GSCM to Site
Balcones Ranch Apartments	55%	128%	11%
Glazer's Wholesale Distributors	72%	103%	3%
Villas on Sixth Apartments	76%	231%	15%
Post South Lamar Apartments	81%	123%	5%
Galileo at 25th Condominiums	91%	157%	4%

Conclusion

From the start, these case studies had limitations. For example, the sites of interest are existing, even though the regulation would take effect for new development. There was no economically feasible way for the Watershed Protection Department to try to develop its own site plans for new development in Austin. This task would have taken longer to accomplish. It may be beneficial to redesign the existing sites, keeping the building shape but not necessarily its location on the site. Being able to site plan and grade surfaces in the beginning stages of a development should increase the site efficiency in terms of developable land and location of GSCMs.

The soil studies, the most determining factor for the use of GSCMs on sites, were conducted using online estimates. No in-situ testing was done to verify soil properties. Although the properties may have been close to speculation, they still provided a variety of hypothetical configurations of GSCMs. For the purposes of these case studies, this would suffice.

All GSCMs were structured based on criteria in Austin's Environmental Criteria Manual Section 1.6.7, but the measure of beneficial use volume is based in theory. Measures were primarily based on the infiltration of a ponding depth or the infiltration of an irrigation rate. There was no way to combine the two for a possible increase in beneficial use volume. In addition, there was no proven way to model the water taken up by plants through transpiration.

Overall, I believe these case studies are very insightful as to how effectively GSCMs can be used on sites in Austin. Taking Glazer's Wholesale Distributors as a special case, it wasn't until about an 80% impervious cover level that using GSCMs became onerous for the property owner. It would be interesting to explore whether developments of this intensity could recoup the costs of the necessary GSCMs, like intensive rainwater reuse and green roofs. Beneficial use requirements would be an aggressive stance on stormwater management in Austin, if maintained throughout the CodeNEXT process.

Austin released Draft 2 of CodeNEXT in September 2017, shortly after the end of my internship. The only addition made to Draft 2.0 was specifying that green infrastructure would be used to achieve beneficial use volumes.[18] There was not enough time for the Watershed Protection Department to synthesize the results of the case studies into Draft 2.0.

In Draft 3.0 released in February 2018, the idea of a beneficial use volume was scrapped in favor of requiring new developments to treat their water quality volume using GSCMs listed in the Environmental Criteria Manual. There are some tentative exceptions for new residential subdivisions, sites with highly contaminated soils or sites that are not currently treating stormwater. Other water quality controls can be used in those cases. Sites with 80% impervious cover or more can use rainwater harvesting to meet on-site irrigation demand.[19] It is unclear if such sites can use other water quality controls that are not GSCMs.

I believe this version of stormwater regulation simplifies the beneficial use requirements while maintaining a protective and restorative potency. I believe his regulation will greatly increase ecosystem services in the Austin urban environment. Furthermore, it is my opinion that new subdivisions should have to use large scale GSCMs in treating stormwater. However, overall the regulation is a leap in the direction of true sustainability. The stakes are high for the final version of the land development code that passes through the CodeNEXT process.

[18] City of Austin. (2017, September). Land Development Code Draft 2.0. CodeNEXT. 3D-6 p. 2
[19] City of Austin. (2018, February). Land Development Code Draft 3.0. CodeNEXT. 3D-6 p. 2

Appendix: Maps

Figure 1: Location of Each Case Study Site

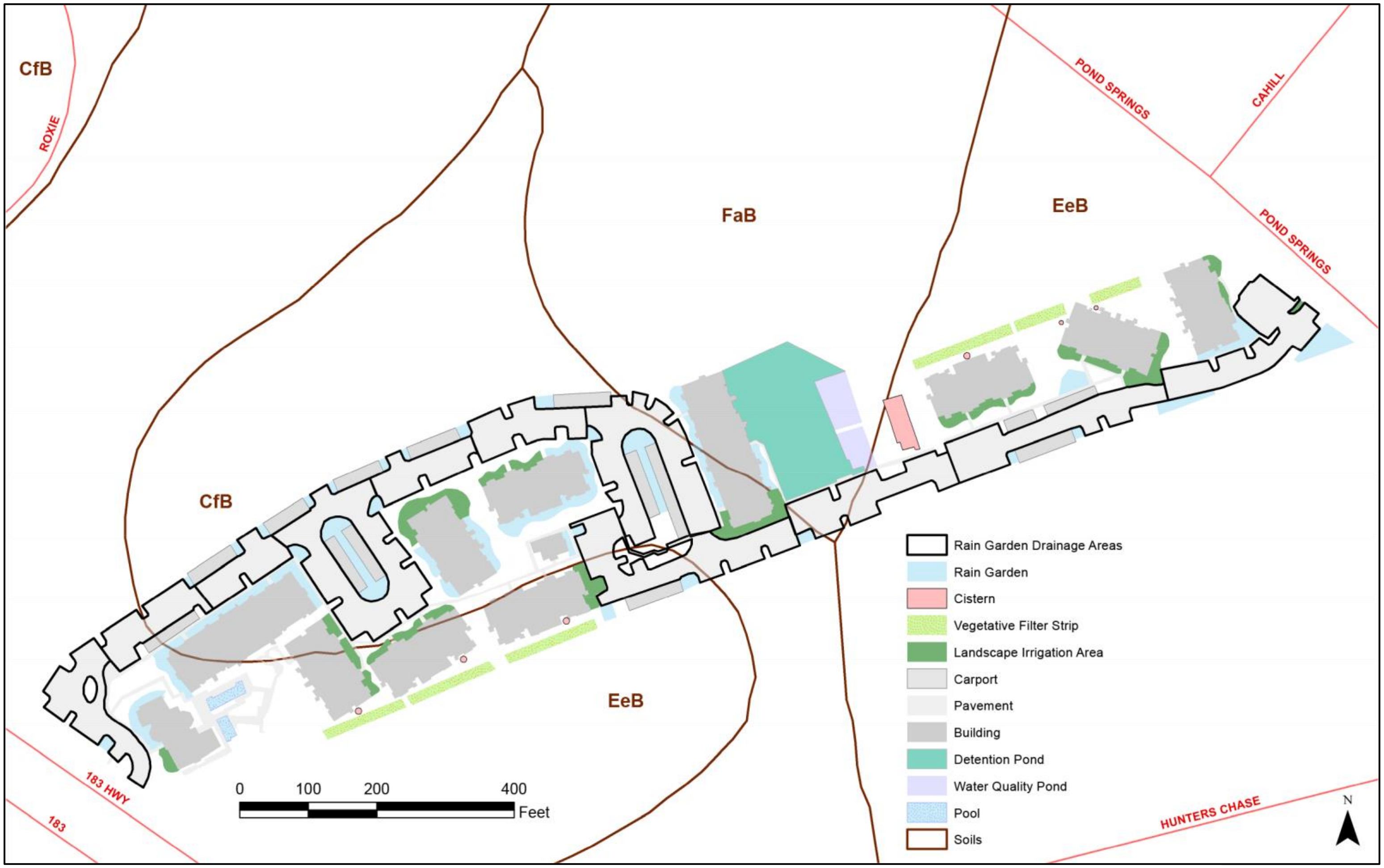

Figure 2: Layout of GSCMs Under Actual Site Conditions for the Balcones Ranch Apartments

Figure 3: Layout of GSCMs Under Ideal Site Conditions for the Balcones Ranch Apartments

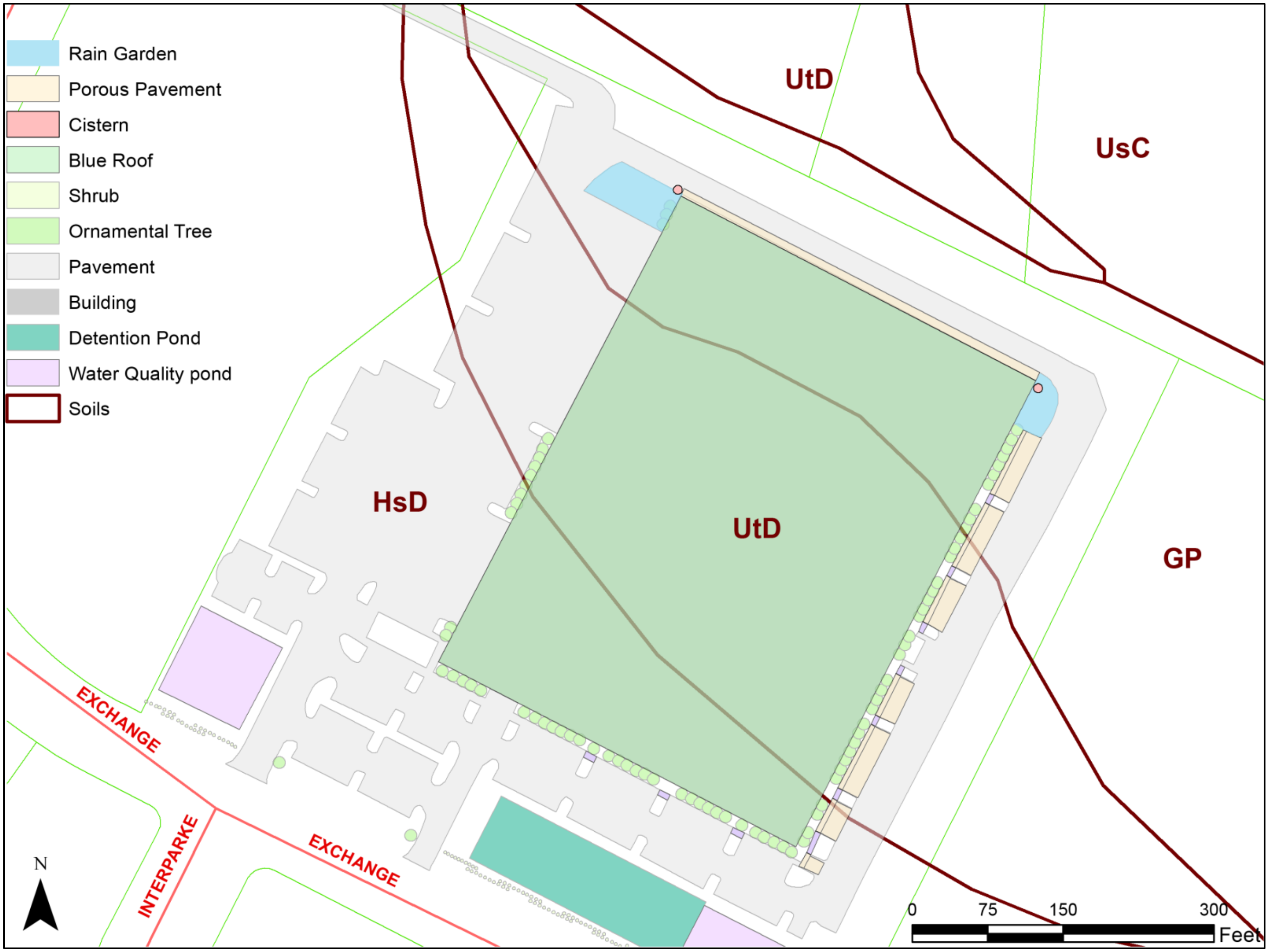

Figure 4: Layout of GSCMs Under Actual Site Conditions for Glazer's Wholesale Distributors

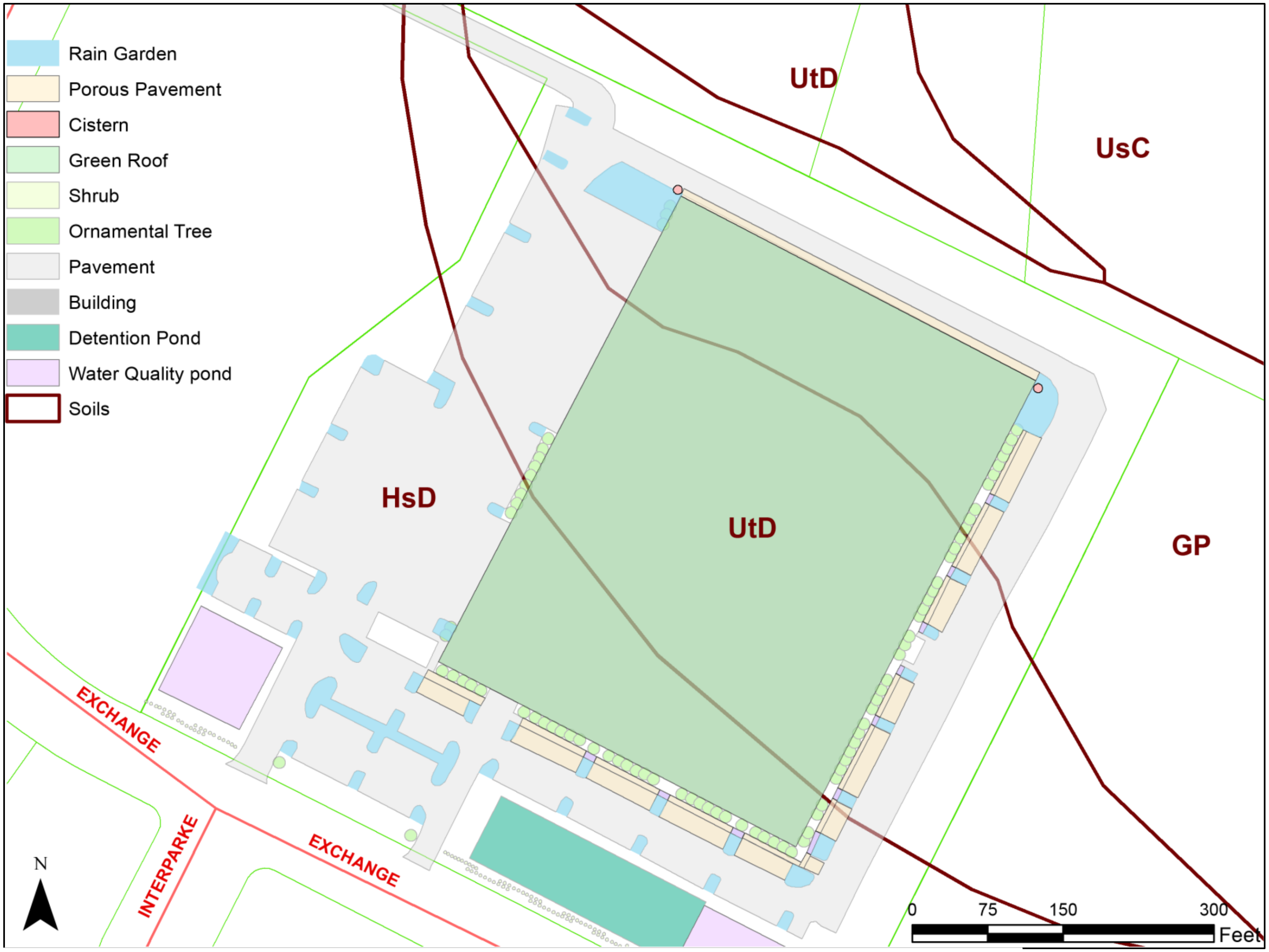

Figure 5: Layout of GSCMs Under Ideal Site Conditions for Glazer's Wholesale Distributors

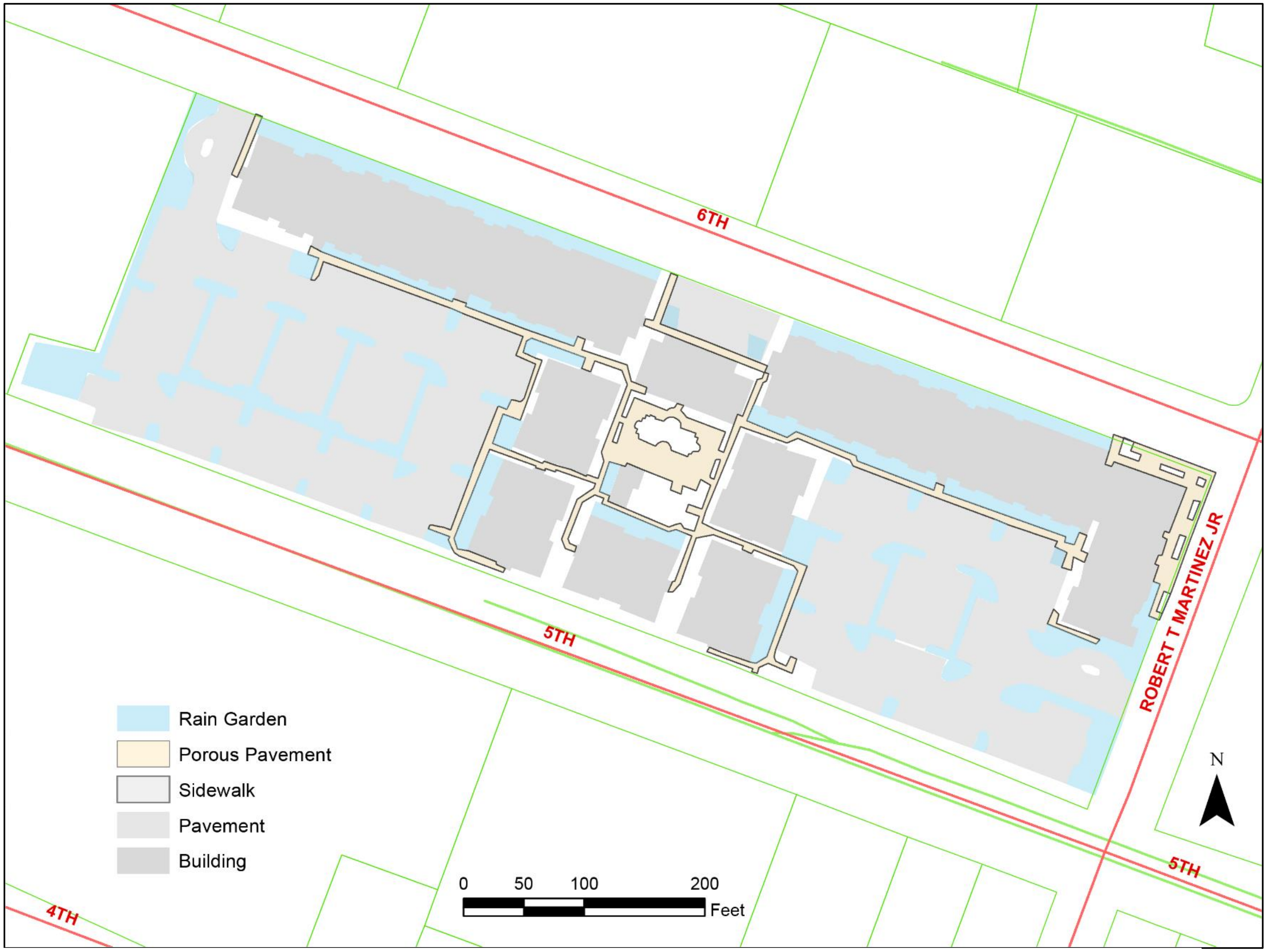

Figure 6: Layout of GSCMs Under Actual & Ideal Site Conditions for the Villas on Sixth Apartments

Figure 7: Layout of GSCMs Under Actual Site Conditions for the Post South Lamar Apartments

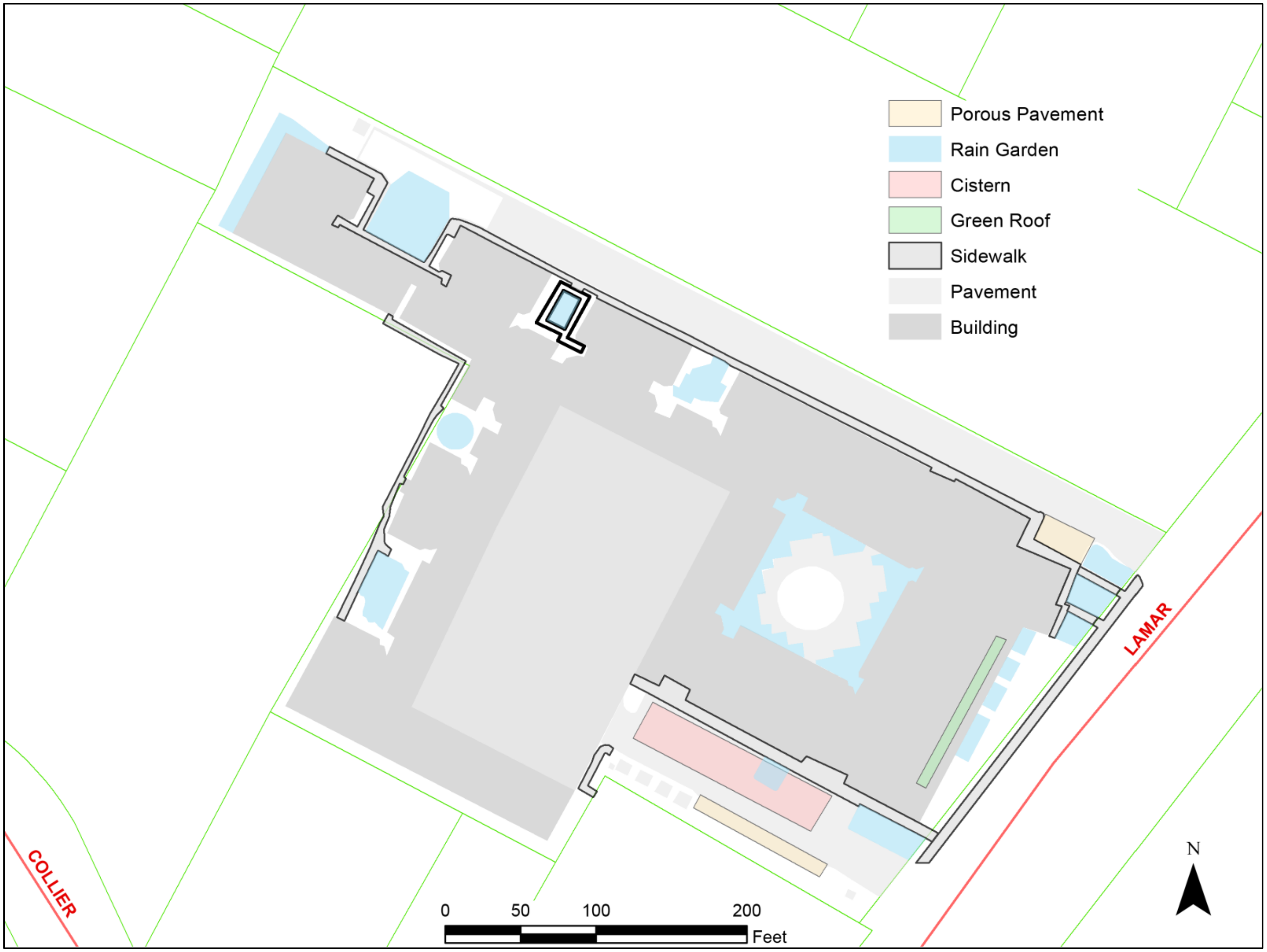

Figure 8: Layout of GSCMs Under Ideal Site Conditions for the Post South Lamar Apartments

Figure 9: Layout of GSCMs Under Actual Site Conditions for the Galileo at 25th Condominiums

Figure 10: Layout of GSCMs Under Ideal Site Conditions for the Galileo at 25th Condominiums

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Vita

Michael William Simmons was born in Anchorage, Alaska. During his childhood, his family relocated to Allen, Texas, for several years, and they finally settled in Missouri City, Texas in 2002. After graduating from the engineering academy at Hightower High School in Missouri City in 2012, Michael went on to pursue a Bachelor of Science in civil engineering at the Cockrell School of Engineering at the University of Texas at Austin, graduating in May 2016. During his time as an undergraduate, Michael discovered his passion for environmental sustainability and community outreach. In August 2016, he began his graduate education in Community and Regional Planning at the University of Texas at Austin.

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This report was typed by the author.